

LHC PHYSICS

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Abstract

The LHC is expected to resume later this year. Though results at the Tevatron make it more difficult for the LHC to pick out Higgs bosons, there are other results which are expected. Some of these are surveyed here.

1 Introduction

The four billion US dollars Large Hadron Collider (LHC) that was launched in September 2008 was eagerly awaited by the physics community. In spite of the tragic accident which may render the LHC disfunctional till 2010, there are several expectations. It is known that the standard model is in excellent agreement with experiments at energies around or less than 200GeV . This is a theory of weak and electromagnetic interactions. However this is not the whole story ([1, 2] and references therein). There are some important unanswered questions. These include the question why the elementary particles have the masses which they are experimentally known to have, that is the question of the mass spectrum. There is also the case of the elusive Higgs Boson which is required in the theory for generating the mass of the particles. The Higgs Boson, despite several attempts, has not turned up. Could the *LHC* discover the Higgs Boson? Equally interesting, what if the Higgs Boson were not discovered even by the *LHC*? This possibility has become more ominous after the recent discovery that the Higgs boson does not have a mass between 160 and 170GeV , at the Tevatron in the US [3]. This is because the LHC is suited for such high energies and not the lower energies

where other colliders like the Tevatron have been operating.

Then there are subtler issues. For instance the dominance of matter over anti matter in the universe—this observational fact requires CP Violation, which indeed was observed way back in 1964 in the decay of the K meson and subsequently in the decay of particles like hyperons. Though this is in agreement with the standard model, it does not still explain the observed matter-anti matter ratio. In other words we need further sources of CP Violation.

Another important issue is that of Supersymmetry (SUSY). Though this has been an elegant theory which has even threatened to solve the as yet unsolved problem of the unified description of General Relativity and Quantum Theory, the fact is that it predicts a whole range of Supersymmetric particles which have not yet been detected. If some or all of these particles are detected by the LHC , that would be a major headway in Particle Physics and Quantum Gravity.

All this including the question of a Neutrino Mass would constitute what has been come to be known as physics beyond the standard model. This would also include the new paradigm of Dark Energy, which was indirectly detected through the acceleration of the universe by an observation of distant supernovae in 1998. Indeed the author's 1997 model had predicted this new cosmological scenario (Cf.ref.[4] and references therein). So it is no wonder that so many hopes are pinned on the LHC .

Finally there is also the related problem of Scale Invariance. This is a well studied problem, at least mathematically, in which we require that the physical laws remain unchanged if the length or energy scale of the problem is multiplied by some factor. However it has not been found as yet in the standard model. It appears that we may require what are called un particles for this to be the case as pointed out by Georgi [5].

In any case the LHC is bound to come up with as yet unknown particles. It is interesting that the author's 2003 mass spectrum formula viz.,

$$m_P = m \left(n + \frac{1}{2} \right) m_\pi \quad (1)$$

gives the mass of all known elementary particles with an error of less than three percent. In the above equation m_P is the mass of the elementary particle in question and m_π is the mass of the π meson and m and n are positive integers. It is derived based on the QCD potential [6, 1, 2]. It gives the mass of all the known elementary particles with an error of about three percent or less. The subsequently discovered $Ds(2317)$ and the as yet

unconfirmed 1.5GeV Pentaquark as also the $Ds(2632)$ and the more recent 4.43GeV meson, the so called Z charged mesons are also described by the above formula. It would be interesting to see if the new particles which are bound to be discovered by LHC would obey the formula (1).

Another effect that can possibly be indirectly tested is that of a non-zero mass for the photon. there is a long history of the fact that the photon can also be considered to be a particle with suitably small mass without contradicting conventional theory, as shown by Deser [7]. In face De Broglie too believed that the photon has a small mass, starting from his work of 1940 and 1942 [8, 9]. Later this work was carried on by Vigier and De Broglie [10]. What has happened is that experimental limits on the mass of the photon have been given, the best so far being [11],

$$m_\gamma < 10^{-57} gm \quad (2)$$

The author has argued over the years that the photon has a mass $\sim 10^{-65} gms$, reaching this conclusion from different viewpoints, but all of them originating in the fact that spacetime is fuzzy and that there is a minimum spacetime interval within which there is no meaningful physics [12, 13](Cf.ref.[2] and references therein),[14, 15]. Interestingly this figure for the photon mass coincides with a minimum mass in the universe deduced purely on the basis of thermodynamical considerations [16].

2 Proton Proton Collisions

In the LHC, protons will collide with protons, ultimate at energies reaching 14TeV in the centre of mass system. In earlier proton proton collisions at lower energies, as is well known, the total cross section was seen to be fairly constant, thus exhibiting a classical behavior. It is expected that in high energy collisions, the wavelength of the protons would be small compared to the range of forces so that the total cross section would be of the order of r_{pp}^2 , the square of the range of the proton proton forces.

Let us now consider the case where the photon can have a small mass. In this case the Coulomb potential becomes a Yukawa potential

$$\frac{1}{r} \rightarrow \frac{e^{-\mu r}}{r} \quad (3)$$

Unlike the Coulomb potential this Yukawa potential given in (3) is in principle a short range force (though in this case, the range would be $\sim 10^{28}cm$,

the radius of the universe) and can be treated by a well known theory. In this case we have

$$f(\Theta, \phi) = -\frac{1}{k} \int_0^\alpha r U(r) \sin kr dr \quad (4)$$

Where

$$\begin{aligned} I &= I_m \int e^{-\lambda r} e^{ikr} dr \\ &= I_m \int_0^\alpha e^{-(\lambda - ik)r} dr \\ &= I_m \frac{1}{(\lambda - ik)} = I_m \frac{(\lambda + ik)}{\lambda^2 + k^2} \end{aligned} \quad (5)$$

This is because, as is known in the high energy case the Born approximation is good [17, 18]

$$f = \frac{1}{k} \cdot \frac{k}{\lambda^2 + k^2} = \frac{1}{\lambda^2 + k^2} \approx \frac{1}{k^2} \quad (6)$$

Further more it can also be shown that [19]

$$\delta_{l+1} = \frac{1}{2}(\delta_l + \delta_{l-1}) \quad (7)$$

Interestingly for protons at very high energies it is known [20, 21, 22, 23], we have instead of the usual relativistic Hamiltonian, the Snyder-Sidharth Hamiltonian given by

$$E^2 = p^2 + m^2 + \alpha l^2 p^4 \quad (8)$$

In (8) l is a minimum fundamental length which is usually taken to be of the order of the Planck length, and α is a positive constant of order less than or equal to 1. Equation (8) shows that effectively the energy, for a high energy approach of the protons jumps from the usual E^2 or k^2 to $E^2 + \delta E$ or $k^2 + \delta k$. This would be reflected in (6).

Finally we remark that in the case where (6) is valid, it is known that for the energies given by (Cf.ref.[24])

$$C_l \approx B_l \quad (9)$$

we would have

$$\delta_l \approx \pi/2 \quad (10)$$

indicating a peak for the corresponding partial cross section. In (9), C_l and B_l are given by:

$$B_l = \int_0^\alpha [r j_l(kr)]^2 U(r) dr,$$

$$C_l = \int_0^\alpha r j_l(kr) U(r) \left[kr n_l(kr) \int_0^\alpha \{r' j_l(kr)\}^2 U(r') dr' \right. \\ \left. + kr j_l(kr) \int_r^\alpha r'^2 j_l(kr') n_l(kr') U(r') dr' \right] dr$$

$j_l(kr)$ and $n_l(kr)$ being the usual spherical Bessel functions.

3 Another Simple Model for pp Collisions

Using the SS-Hamiltonian (8) it was argued by the author [25] that the Dirac equation gets an extra term which does not conserve parity. Starting from this modified Dirac equation it can be argued [26] that in the ultra relativistic limit, we encounter the negative energy solutions in the form of an antiparticle with a slightly shifted energy. In other words the extra parity non conserving term in the Dirac equation can be compared with the magnetic field which splits energy levels in the Zeeman effect. From the scattering point of view, an onrushing proton on to another proton encounters, in the simplest terms, a dipole, that is the potential is given by

$$U(r) = \frac{\lambda}{r^2} \quad (11)$$

The potential (11) has many peculiarities and has been studied in detail [27, 28]. The wave function is given by

$$u = \left(\frac{\pi}{2ik} \right)^{\frac{1}{2}} \left[\frac{e^{p\pi}}{\sinh(\pi p)} J_p(ikr) - \frac{1}{\sinh(\pi p)} J_p(ikr) \right] \quad (12)$$

The solution (12) shows that for a certain range of λ (into which the angular momentum coefficient of potential scattering viz., $l(l+1)$ can be absorbed) greater than λ_0 , there is a continuum of bound states, which however can be artificially discretized by imposing orthogonality conditions. In other words the strength of the potential destroys the Quantum characteristics of the problem, and makes it classical. In this latter case, we know that the classical treatment yields for scattering, results identical to that of non relativistic Quantum theory [29].

So even though we are in the ultra relativistic region, as can be expected in the LHC, we can use the formula for the phase-shifts from the usual theory [18], viz.,

$$\delta_l = \lambda k B_l + \lambda^2 k C_l \quad (13)$$

where B_l and C_l are as above. There is a further peculiarity for the specific form of the potential, given in (11) viz., $C_l = 0$ [30] and (13) reduces to the first Bohm approximation (Cf.ref.[18]). We can easily verify that (13) gives, in the case $l = 0$ (the largest phase-shift) that δ_l is given by

$$\delta_l \sim \text{independent of } k \quad (14)$$

4 Remarks

We would like to finally point out that it is possible to get new fine structure energy levels for Hydrogenic atoms with the Yukawa potential (3) replacing the usual Coulomb potential [31].

We proceed as follows:

Let us introduce the Yukawa potential,

$$V(r) = \alpha e^{-\mu r}/r \quad (15)$$

into the Dirac equation instead of the usual Coulomb potential [32]. In (15), μ is proportional to the mass of the photon $\sim 10^{-65} gms$ and is therefore a very small quantity. We introduce (15) into the stationary Dirac equation to get

$$[c\vec{\alpha} \cdot \vec{p} + \beta m_0 c^2 - (E - V(r))]\psi(r) = 0 \quad (16)$$

From (16) and (15), we can immediately see that roughly the effect of the photon mass is to shift the energy levels by a miniscule amount.

We further introduce the notation

$$Q = 2\lambda r, \quad \text{where } \lambda = \frac{\sqrt{m_0^2 c^4 - E^2}}{hc}, \quad (17)$$

After the standard substitutions (Cf.ref.[32]) we finally obtain

$$\begin{aligned} \frac{d\Phi_1}{dQ} &= \left(1 - \frac{\alpha E}{hc\lambda Q}\right) \Phi_1 - \left(\frac{\chi}{Q} + \frac{\alpha m_0 c^2}{hc\lambda Q}\right) \Phi_2, \\ \frac{d\Phi_2}{dQ} &= \left(-\frac{\chi}{Q} + \frac{\alpha m_0 c^2}{hc\lambda Q}\right) \Phi_1 + \left(\frac{\alpha E}{hc\lambda Q}\right) \Phi_2 \end{aligned} \quad (18)$$

The substitutions

$$\Phi_1(Q) = Q^\gamma \sum_{m=0}^{\infty} \alpha_m Q^m,$$

$$\Phi_2(Q) = Q^\gamma \sum_{m=0}^{\infty} \beta_m Q^m. \quad (19)$$

in (18) leads to

$$\begin{aligned} \alpha_m(m + \gamma) &= \alpha_{m-1} - \left(\frac{\alpha E}{\hbar c \lambda} \right) \alpha_m - \left(\chi + \frac{\alpha m_0 c^2}{\hbar c \lambda} \right) \beta_m, \\ \beta_m(m + \gamma) &= \left(-\chi + \frac{\alpha m_0 c^2}{\hbar c \lambda} \right) \alpha_m + \left(\frac{\alpha E}{\hbar c \lambda} \right) \beta_m. \end{aligned} \quad (20)$$

As is well known γ in (19) is given by

$$\gamma = \pm \sqrt{\chi^2 - \alpha^2}, \quad (21)$$

where λ is given by (17).

At this stage we remark that the usual method adopted for the Coulomb potential is no longer valid - mathematically, Sommerfeld's polynomial method becomes very complicated and even does not work for a general potential: We have to depart from the usual procedure for the Coulomb potential in view of the Yukawa potential (15). Nevertheless, it is possible to get an idea of the solution by a slight modification. This time we have from (20), instead the equations

$$\begin{aligned} \alpha_m(m + \gamma) &= \alpha_{m-1} - \frac{\alpha E}{\hbar c \lambda} \alpha_m + \frac{\alpha E \mu}{\hbar c \lambda} \alpha_{m-1} \\ (-\chi \beta_m) - \frac{\alpha m_0 c^2}{\hbar c \lambda} \beta_m + \frac{\mu \alpha m_0 c^2}{\hbar c \lambda} \beta_{m-1} \end{aligned} \quad (22)$$

and

$$\begin{aligned} (m + \gamma) \beta_m &= - \left(\chi + \frac{\alpha m_0 c^2}{\hbar c \lambda} \right) \alpha_m - \frac{\mu \alpha m_0 c^2}{\hbar c \lambda} \alpha_{m-1} \\ &\quad + \frac{\alpha E}{\hbar c \lambda} \beta_m - \frac{\mu \alpha E}{\hbar c \lambda} \beta_{m-1} \end{aligned} \quad (23)$$

After some algebra on (22) and (23) we obtain

$$P \alpha_m + Q \beta_m = R \alpha_{m-1} \quad (24)$$

$$S \alpha_m + T \beta_m = U \beta_{m-1} \quad (25)$$

where P, Q, S, T can be easily characterized, in the derivation of which we will neglect μ^2 and higher orders.

If

$$\alpha_m/\beta_m \equiv p_m$$

then we have from (24) and (25),

$$Sp_m + T = \frac{U(QS - PT)}{(RSp_{m-1} - PU)}$$

We note that the asymptotic form of the series in (19) will not differ much from the Coulomb case and so we need to truncate these series. For the truncation of the series we require

$$QS = PT$$

This gives

$$\begin{aligned} & \left\{ 1 + \frac{\chi \hbar c \lambda}{\alpha m_0 c^2} \right\} \left[E \left(\chi + \frac{\alpha m_0 c^2}{\hbar c \lambda} \right) + m_0 c^2 \left(m + \gamma - \frac{\alpha E}{\hbar c \lambda} \right) \right] \\ &= \left(m + \gamma - \frac{\alpha E}{\hbar c \lambda} \right) \frac{\hbar c \lambda}{\alpha m_0 c^2} \left[E \left(m + \gamma + \frac{\alpha E}{\hbar c \lambda} \right) + m_0 c^2 \left(\chi + \frac{\alpha m_0 c^2}{\hbar c \lambda} \right) \right] \end{aligned}$$

Further simplification yields

$$(m + \gamma)^2 + \left\{ \frac{\chi \hbar c \lambda + \alpha m_0 c^2}{\hbar c \lambda} \right\}^2 + \frac{\alpha^2 E^2}{\hbar^2 c^2 \lambda^2}$$

where γ is given by (21). Finally we get, in this approximation,

$$E^2 = m_0^2 c^4 \left[1 - \frac{2\alpha^2}{\alpha^2 + (m + \gamma)^2 - \chi^2} \right] + AO\left(\frac{1}{m^2}\right) \quad (26)$$

In (26) A is a small quantity

$$A \sim m_0^2 c^4 - E^2$$

The second term in (26) is a small shift from the usual Coulombic energy levels. In (26) m is a positive integer and this immediately provides a comparison with known fine structure energy levels. To see this further let us consider large values of m . (26) then becomes

$$E = m_0 c^2 \left[1 - \frac{\alpha^2}{m_1^2} \right] \quad (27)$$

while the usual levels are given by

$$E = m_0 c^2 \left[1 - \frac{\alpha^2}{2m_2^2} \right] \quad (28)$$

We can see from (27) and (28) that the photon mass reproduces all the energy levels of the Coulomb potential but interestingly (27) shows that there are new energy levels because m_1^2 in the new formula can be odd or even but $2m_2^2$ in the old formula is even. However all the old energy levels are reproduced whenever $m_1^2 = 2m_2^2$. If $\mu = 0$, then as can be seen from (16), we get back the Coulomb problem. In any case, the above calculation was suggestive and more to indicate how the problem changes.

References

- [1] Sidharth, B.G. (2005). *The Universe of Fluctuations* (Springer, Netherlands).
- [2] Sidharth, B.G. (2008). *The Thermodynamic Universe* (World Scientific), Singapore.
- [3] (2009). *Nature* 458 (No.7236), p.273, 2009.
- [4] Sidharth, B.G. (2001). *Chaotic Universe: From the Planck to the Hubble Scale* (Nova Science, New York).
- [5] Giri, A.K. (2008). *Current Science* Vol.94, No.10, 25 May 2008 and *Nature Physics*, Vol.3, July 2007, p.446.
- [6] Sidharth, B.G. (2005). *Hadronic Journal* 28, 5, October 2005, pp.599ff and references therein.
- [7] Deser, S. (1972). *Ann Inst. Henri Poincare, Vol.XVI* (Paris, Gauthier-Villors), pp.79.
- [8] De Broglie, L. (1940). *La mecanique ondulatoire du photon Une nouvelle theorie de la lumiere* Vol.I (Paris, Hermann).
- [9] De Broglie, L. (1942). *Les interactions entre les photons et la matiere* Vol.II (Paris, Hermann).

- [10] De Broglie, L. and Vigier, J.P. (1972). *Phys.Rev.Lett.* 28, pp.1001–1004.
- [11] Lakes, R. (1998). *Phys.Rev.Lett.* 80, (9), pp.1826ff.
- [12] Sidharth, B.G., *Found.Phys.Lett.* 19 (4), 2006.
- [13] Sidharth, B.G., *Found.Phys.Lett.* 19 (1), 2006, pp.87ff.
- [14] Sidharth, B.G. *Comments on the Mass of the Photon* to appear in *Annales de La Fondation De Broglie*.
- [15] Sidharth, B.G. *Mass Generation and Noncommutative Spacetime* to appear in *Int.J.Mod.Phys.E.* *arxiv 0811.4541*.
- [16] Landsberg, P.T. (1983). *Am.J.Phys.* 51, pp.274–275.
- [17] Mott, N.F. and Massey, H.S.W. (1965) *The Theory of Atomic Collisions* (Oxford University Press, Oxford), pp.53-68.
- [18] Roman, P. (1965). *Advanced Quantum Theory* (Addison-Wesley, Reading, Mass.), p.31.
- [19] Powell, J.L. and Crasemann, B. (1988). *Quantum Mechanics* (Narosa Publishing House, New Delhi), pp.5ff.
- [20] Sidharth, B.G. (2008). *Foundation of Physics* 38, p.89-95.
- [21] Sidharth B.G. *arXiv Physics 0902.3342*.
- [22] Glinka L.A. (2008). *Apeiron* 2, April 2008; *arXiv hep-ph 0812.0551*
- [23] Glinka L.A. *arXiv 0902.4811 v2*.
- [24] Sidharth, B.G. (1975). *Bull.Cal.Math.Soc.* 67 (3), pp.137ff.
- [25] Sidharth, B.G. (2005). *Int.J.Mod.Phys.E* 14 (6), 2005, pp.923ff.
- [26] Sidharth, B.G. *arxiv 0910.2133*.
- [27] Sidharth, B.G. (1981). *Nuovo Cimento* 31 (18), 1981, p.648.
- [28] Morse, P.M. and Feschbach, H. (1953). *Methods of Theoretical Physics* (II) (Mc-Graw Hill Book Co., New York), pp1323.

- [29] Goldstein, H. (1966). *Classical Mechanics* (Addison-Wesley, Reading, Mass.), pp.76ff.
- [30] Sidharth, B.G. (1978). *Nuovo Cimento* 46A, 1978, p.419.
- [31] Sidharth, B.G. *New Fine Structure Energy Levels* to appear in *New Advances in Physics*.
- [32] Greiner, W., Muller, B. and Rafelski, J. (1985). *Quantum Electrodynamics of Strong Fields* (Springer-Verlag, Berlin).